Physics Justification for an ATLAS Phase I Upgrade

DOE/NSF Briefing

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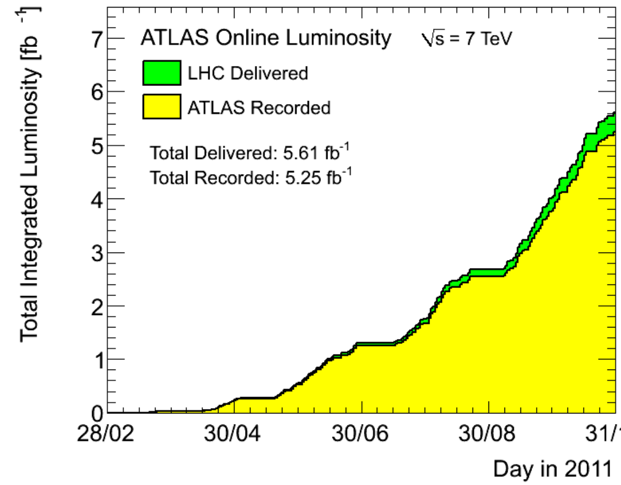
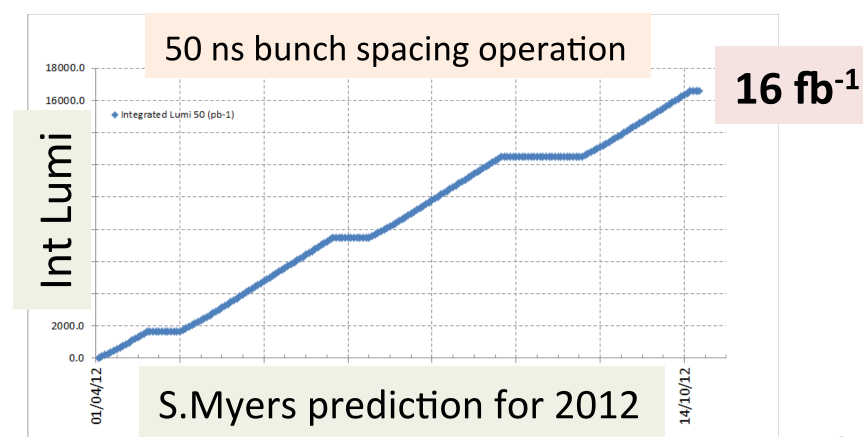
Letter Of Intent Approved by ATLAS Collaboration on Feb. 3, 2012
http://cdsweb.cern.ch/record/1402470

Luminosity Evolution

- 2011:
  - Peak luminosities at ~ 3 x 10^{33} cm^{-2} s^{-1}
    - With 50 ns bunch spacing and $\sqrt{s}$ = 7 TeV
  - Integrated Luminosity delivered = 5.6 fb^{-1}
  - **Delivering beyond expectations!**
- 2012:
  - Expect peak luminosities ~ 7 x 10^{33} cm^{-2} s^{-1}
    - Continue with 50 ns bunch spacing
    - Increase $\sqrt{s}$ = 8 TeV
    - Decisions at Chamonix workshop in January 2012
  - Integrated Luminosity: ~ 15 – 20 fb^{-1} per experiment.
- 2013-2014:
  - Phase 0 shutdown, Upgrades incl:
  - IBL, Beam pipe, LVPS, shielding,

EE muon chambers, cooling/cryo, FTK demo, TDAQ work, LAr/Trigger demo, & several other maintenance.



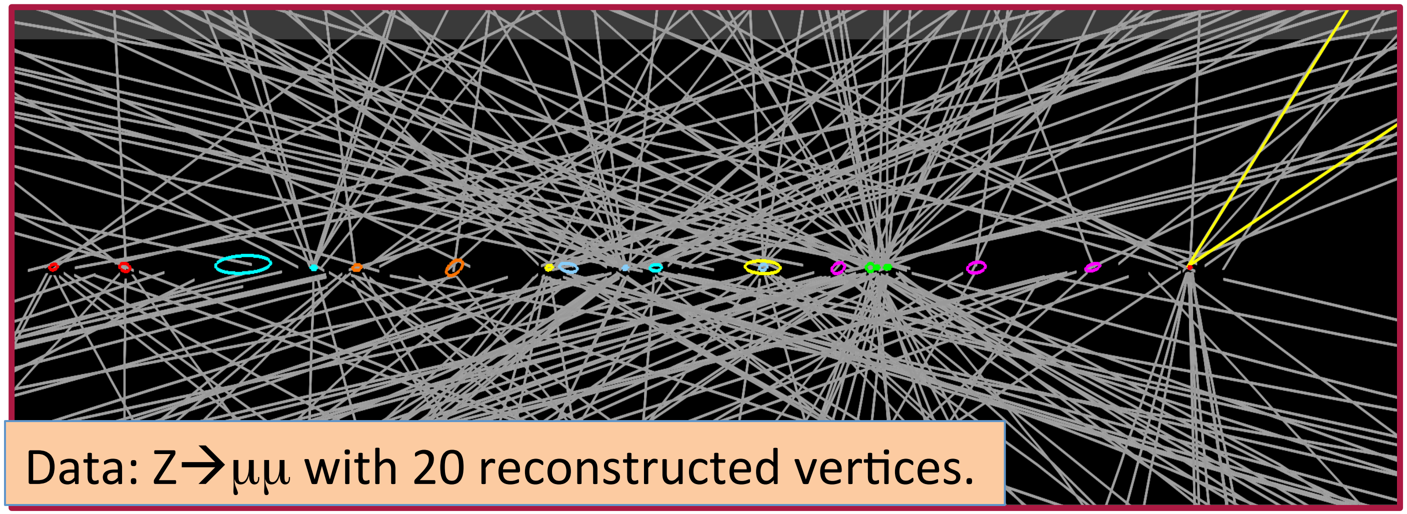


Luminosity Evolution (2)

- 2015 – 2017:
  - Expect operation at or close to design parameters:
  - Peak Luminosity ~ 10^{34} cm^{-2} s^{-1}
  - 25 or 50 ns bunch spacing
  - $\sqrt{s}$ ~ 14 TeV
- 2018: Phase 1 Shutdown
- 2019 – 2021:
  - Expect operations at beyond the design parameters
  - Peak Luminosity : 2 – 3 x 10^{34} cm^{-2} s^{-1} at 25 ns bunch spacing operation
  - Integrated Luminosity: 300 – 400 fb^{-1}
  - Multiple interactions per crossing : 50 – 80 with 25 ns bunch spacing.
  - Need to ensure we have a margin for operations so we can handle beyond these expected conditions.

The (50) million dollar question:

- Can the current system handle the increasing luminosity and pile-up conditions post-Phase 1 shutdown?
  - Preserving the physics of interest.
  - Recall: 2-3 x 10^{34} cm^{-2} s^{-1} with 50-80 interactions/crossing.



Data: Z→μμ with 20 reconstructed vertices.

If not?

What are the limitations?

What cost-effective upgrades can ensure that we maximize the physics reach of ATLAS?

What is the physics of interest?

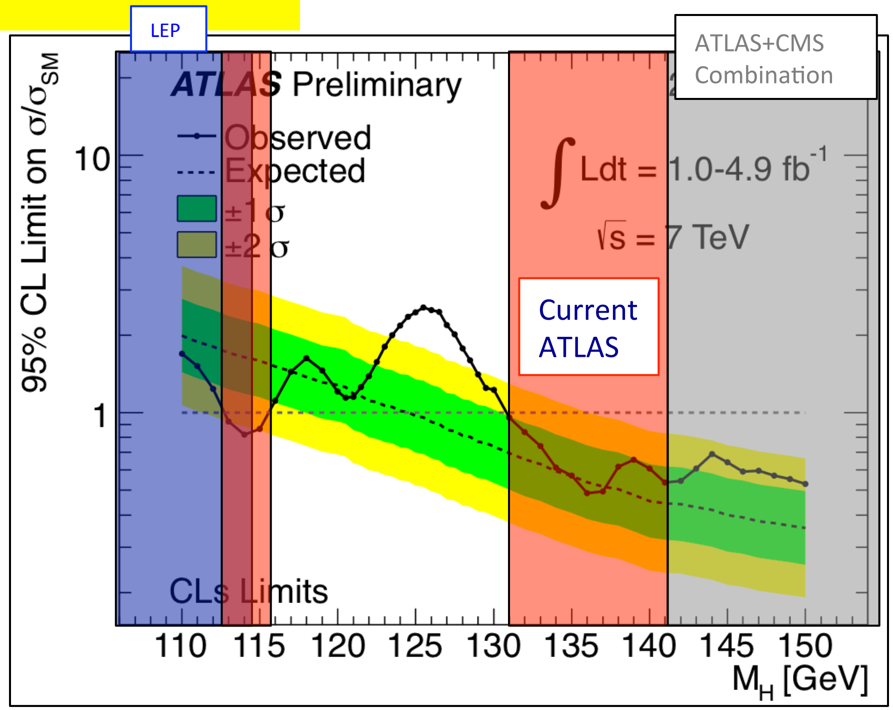
A Standard Model Higgs would have either been:
-- Discovered or ruled out by 2018.

Higgs discovered scenario

- Precision measurements of its mass, width, production rates, branching ratios and couplings to fermions/ bosons
- Using possibly rare processes such as WH → $\ell \nu b\bar{b}$

SM Higgs ruled out

Unitarity violation in WW scattering, which may reveal the principal mechanism of Electroweak symmetry breaking.



Both require low lepton thresholds for an efficient Higgs trigger

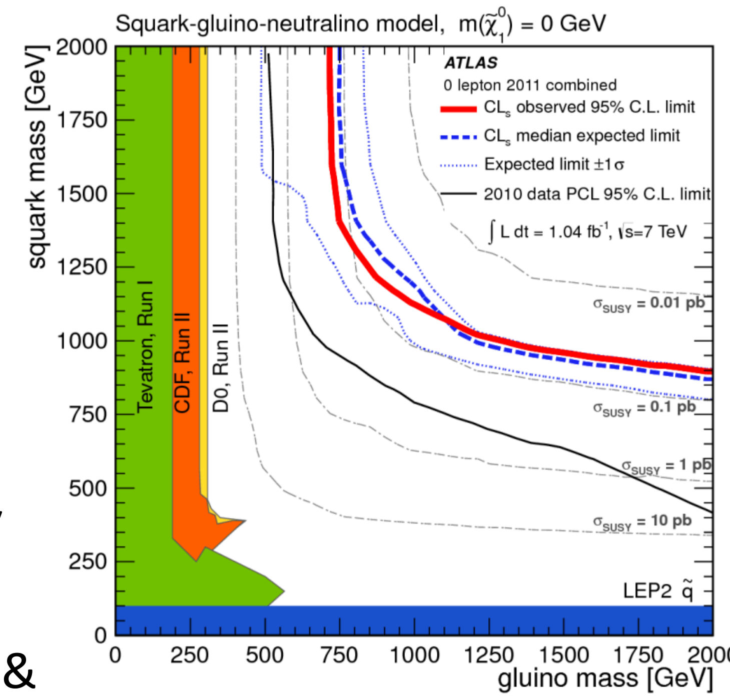
Searches for Supersymmetry

- **Current LHC SUSY constraints:**

  $$m(\tilde{q}),\ m(\tilde{g})\ >\ \sim 1\ \text{TeV}$$

  $$\text{for } m(\tilde{\chi}_0^1) = 0\ \text{GeV}$$

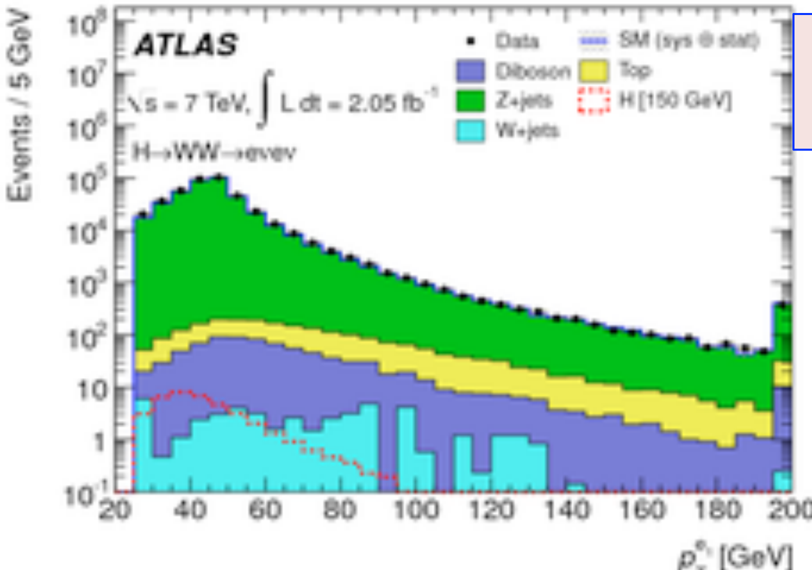
- **Targeted signatures with 300 fb^{-1}:**
  - strong production:
    - squark and gluino cascade decay
    - stop & sbottom production
      - All involving jets, Missing E_T & possible additional leptons.
  - Electroweak production:
    - Direct slepton and gaugino production involving multi-leptons and Missing E_T.



If SUSY is discovered before Phase 1: Need for precision measurements will dominate the priorities.

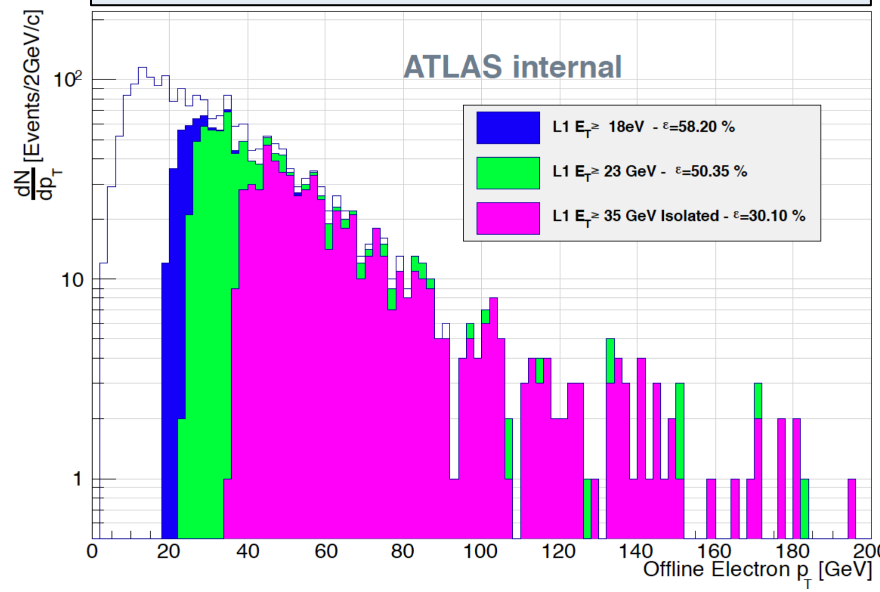
Requires low lepton and jet thresholds
To improve acceptance

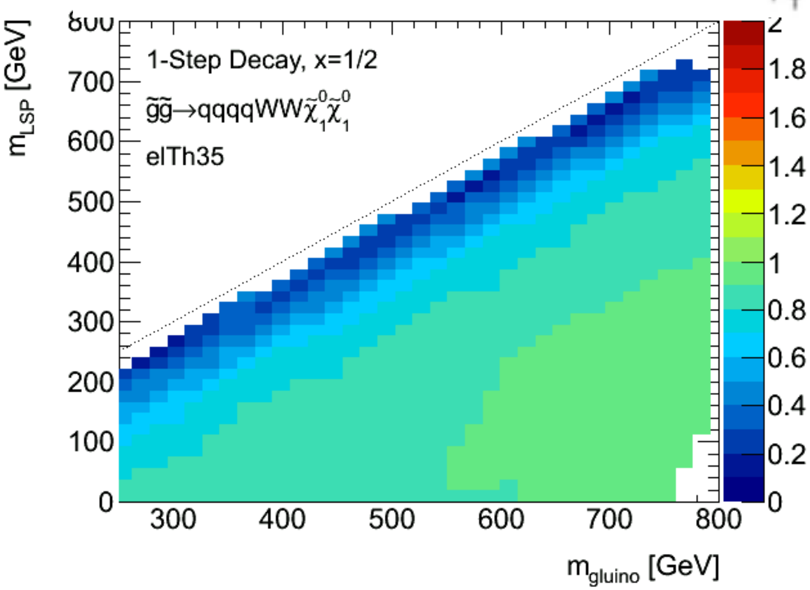
Acceptance to low P_T leptons essential



P_T(leading lep) observed in data compared to SM backgrounds and H(150 GeV)→WW

P_T(lep) from tau decays in H(130)→ττ for increasing P_T trigger thresholds

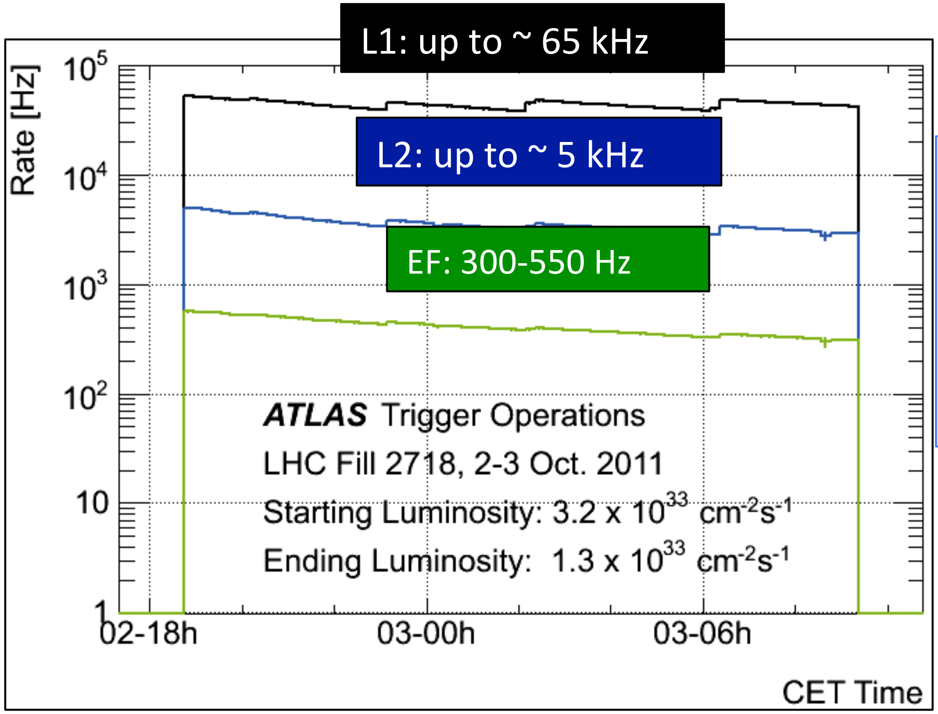




Efficiency Ratio

$$\frac{\text{Eff } [P_T(\text{lep})>35 \text{ GeV}]}{\text{Eff } [P_T(\text{lep})>25 \text{ GeV}]}$$

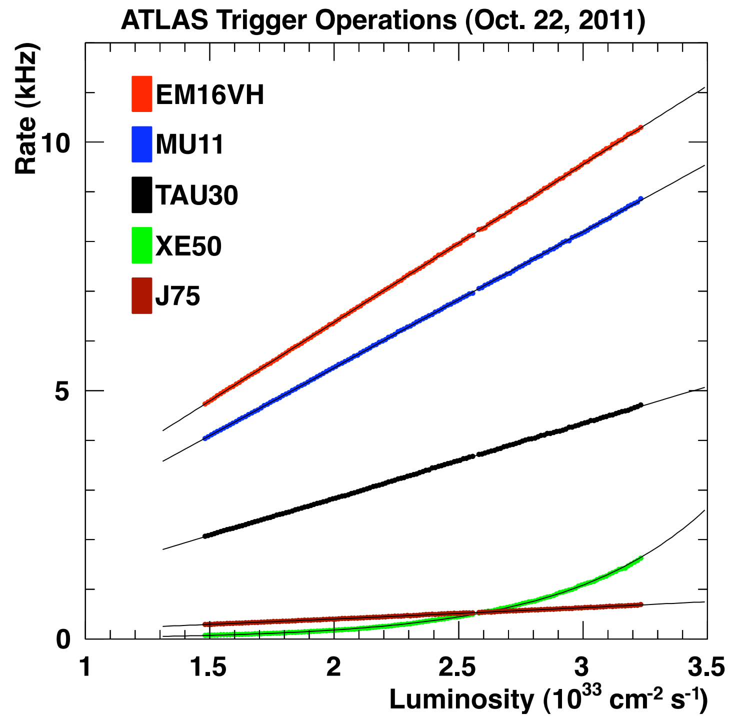
Can we maintain acceptance to low P_T leptons?



L1 total output rate limited to 75(100) kHz
Lowest single electron and muon trigger each use 10-20 % of this bandwidth.
i.e. EM16 (iso) is ~10 kHz at 3 x 10^{33} cm^{-2} s^{-1}
& MU11 is 8 kHz at 3 x 10^{33} cm^{-2} s^{-1}

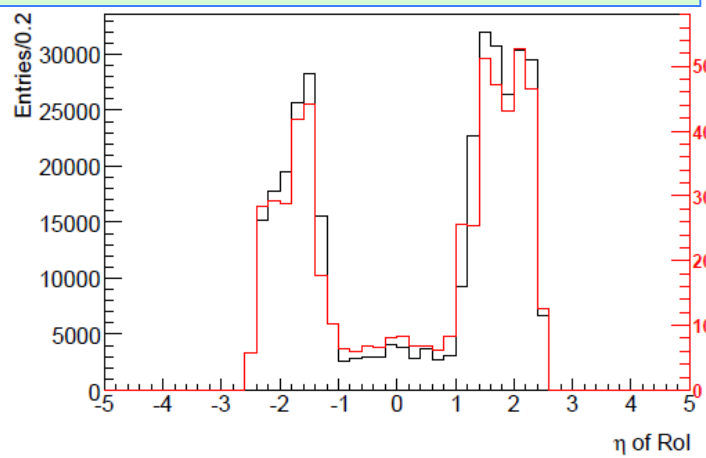
Rates for most triggers increasing linearly with luminosity except Missing E_T (XE) and total scalar E_T (TE) triggers

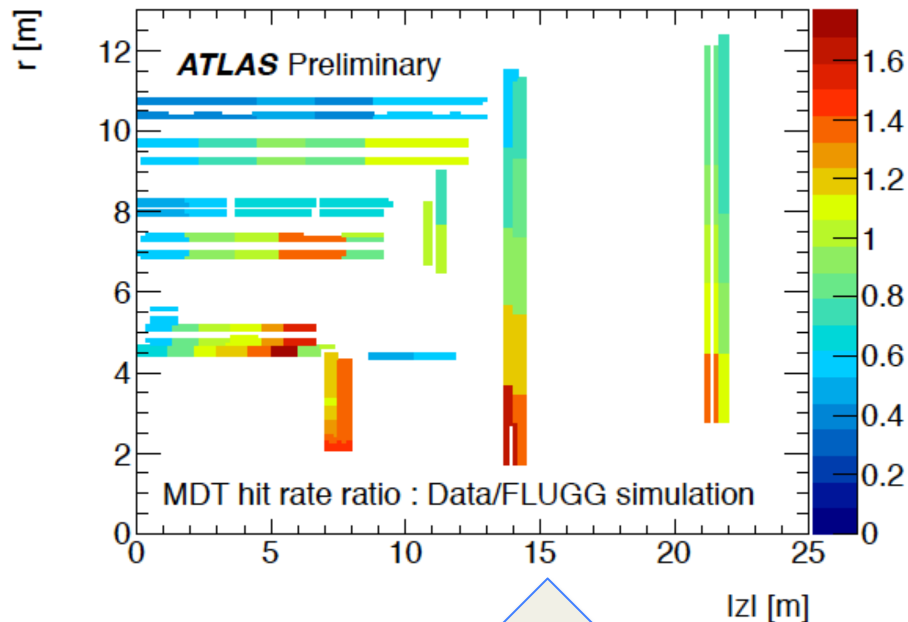
Projected single lepton rate at 2 x 10^{34} cm^{-2} s^{-1}:
Single isolated EM cluster > 23 GeV: ~80 kHz
Single Muon > 20 GeV: ~40 kHz

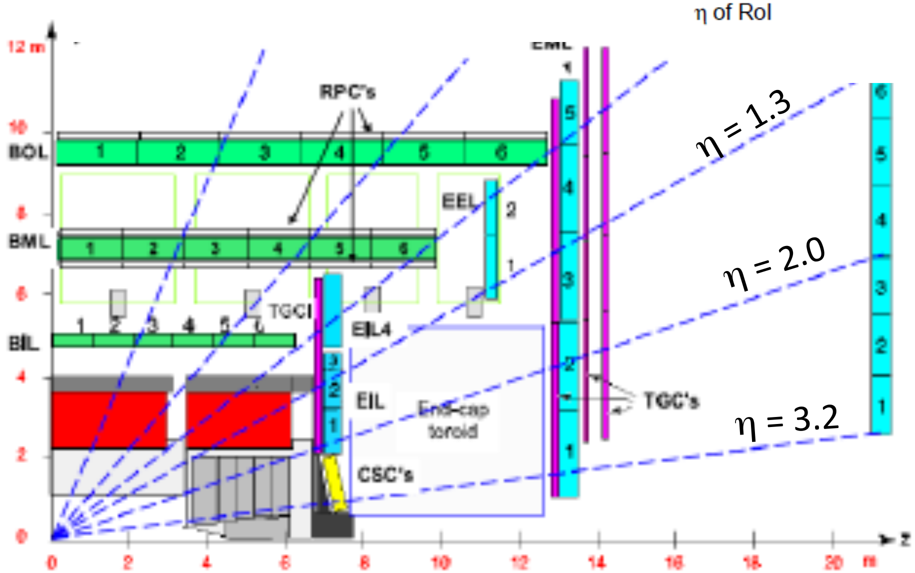


Fake rates are also on the rise:

Muon 20 GeV trigger rate vs Rapidity







Ratio of measured to simulated Muon Drift Chamber (MDT) Hit rate during 2011 7 TeV run

The Phase 1 Upgrade

- Ensure that we can continue to use low P_T thresholds that allows us to keep physics acceptance high and trigger rates in check: The central focus is therefore the trigger.
- Principal Components of the Phase 1 Upgrade:
  - A finer granularity calorimeter trigger readout
    - Allows additional rejection against jets by using finer cluster shape information at Level 1.
  - New small wheel (NSW) muon chambers ($1.3 < |\eta| < 2.7$)
    - Substantial reduction of fakes by providing an additional trigger plane (& pointing to 1 mrad) in the forward region.
  - Topological Processors
    - Selection using the topology of identified objects in an event.

Principal Components (2)

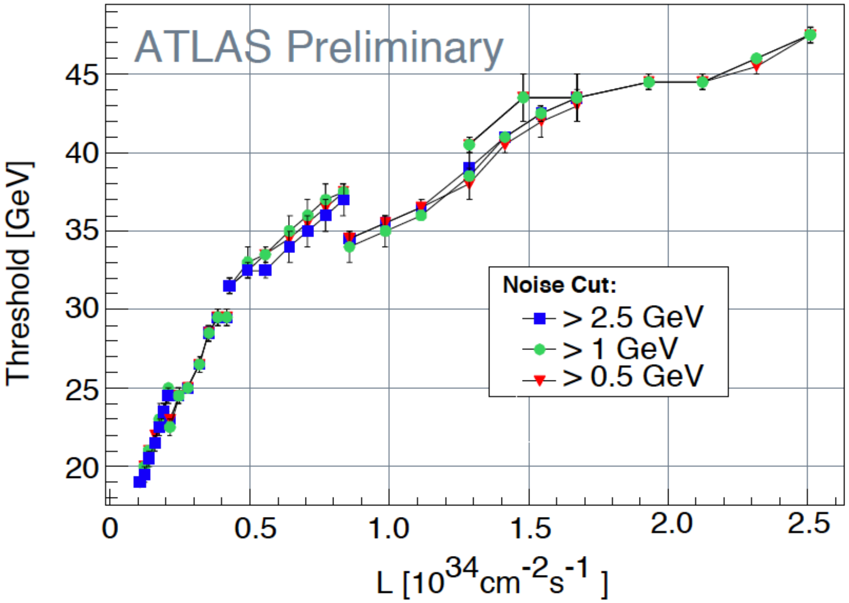
- The Fast Track Trigger (FTK)
  - Provides rapid computation of all tracks in all events accepted by Level 1 and is used in High Level Trigger (HLT).
  - This project is approved and funded by NSF/MRI.
  - Not discussed further in this presentation
- Other Trigger Upgrades
  - Central Trigger Processor (CTP), High Level Trigger (HLT), Level 1 interfaces to DAQ/HLT, and Online Computing upgrades.
- Forward Physics Detector (AFP)
  - Allows tagging of forward tagged protons that provides sensitivity to new physics – including anomalous coupling between γ and W/Z bosons; and diffractive physics beyond the kinematical range of HERA, Tevatron.
  - Inclusion of an ATLAS Forward Proton Detector (AFP)

Finer Granularity Calorimeter Trigger Readout

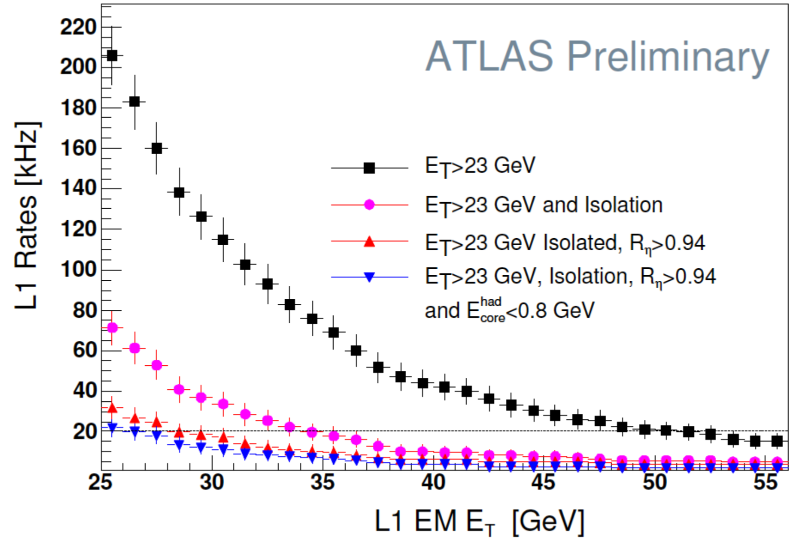
- The current Level 1 calorimeter trigger uses:
  - Transverse Energy thresholds based on $\Delta\eta x \Delta\phi$=0.1 x 0.1 trigger towers
  - Lateral or Longitudinal isolation
  - No direction or sampling level information available.
- A finer granularity trigger readout allows for computation of lateral and longitudinal shower shapes in each sampling of the calorimeter.
  - Provides the much needed additional rejection against QCD background at Level 1
  - Lower thresholds + shape cuts provides better physics acceptance for the same trigger rate than higher thresholds.
- An efficient cut that is used is R_η, the lateral profile in the second sampling around the hottest cell:

$$R_\eta = \frac{\mathrm{E}(\Delta\eta \text{ x } \Delta\phi = 3 \text{ x } 8 \text{ cells})}{\mathrm{E}(\Delta\eta \text{ x } \Delta\phi = 7 \text{ x } 8 \text{ cells})}$$

Rate reduction achievable using finer granularity



Predicted E_T threshold at Level 1 for non-isolated EM objects as a function of luminosity (L) that will yield a 20 kHz output rate.



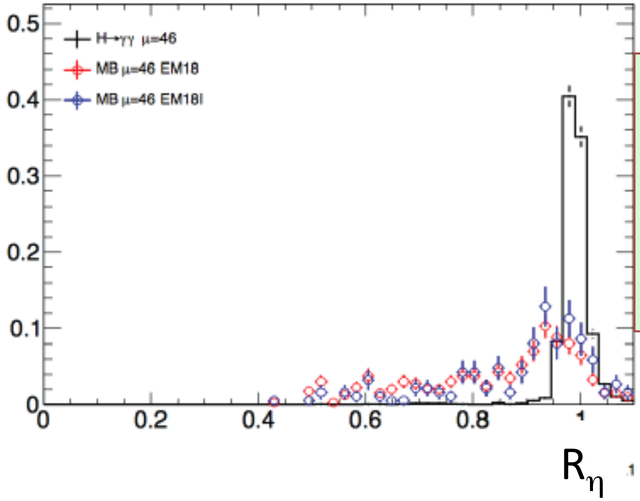
Level 1 Trigger Rate estimated using simulation as a function of E_T threshold at 2 x 10^{34} cm^{-2} s^{-1} with various additional selections, the red and the blue achievable only with an Upgrade

A study of WH associated production: H → $\gamma\gamma$, $b\bar{b}$ or $\tau\tau$ & W → $e\nu$ that relies on a single EM cluster trigger

Trigger	Shape Cuts	Eff (WH)%	Rate (kHz)
EM23	-	93.5	212
EM23I	-	91.7	81
EM35	-	72.8	54
EM35I	-	71.3	16
EM23I	$R_\eta > 0.94$	90	28
EM23I	$R_\eta > 0.94$ + Had. Isolation	88	23

Conclusion: The use of shower shape cuts at Level 1 maintains high physics acceptance at affordable trigger rates.

A study of H→ γγ that relies on a di-EM cluster trigger at Level 1



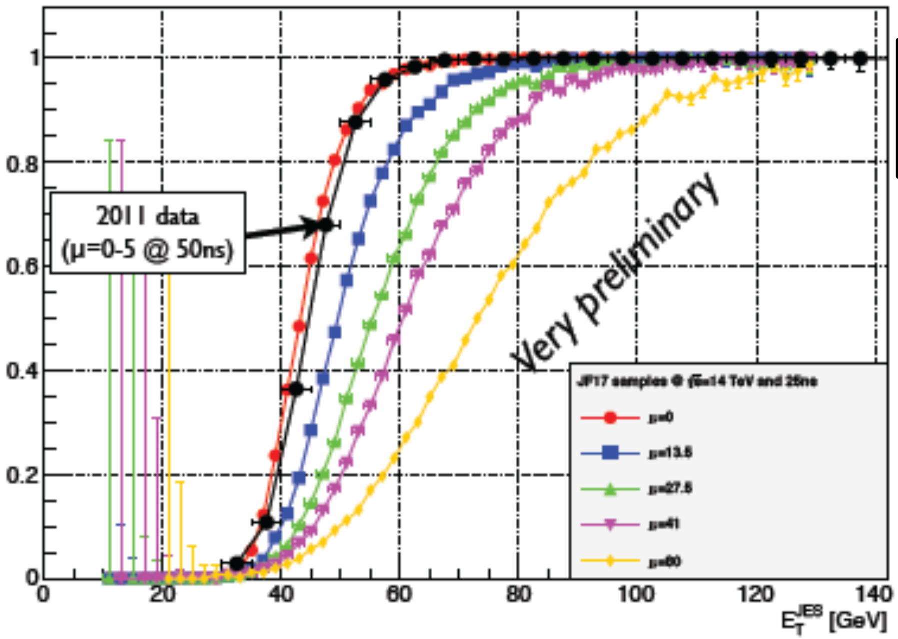
Black: R_η distribution for γ in H→γγ events

Red/Blue: R_η distribution for EM clusters in minimum bias events.

Trigger	R_η	Eff (WH)%	Rate (kHz)
2EM20	-	99.8	12.6
2EM20I	-	96.7	5.0
2EM20	0.80	99.6	4.9
2EM18	0.94	97.9	0.9

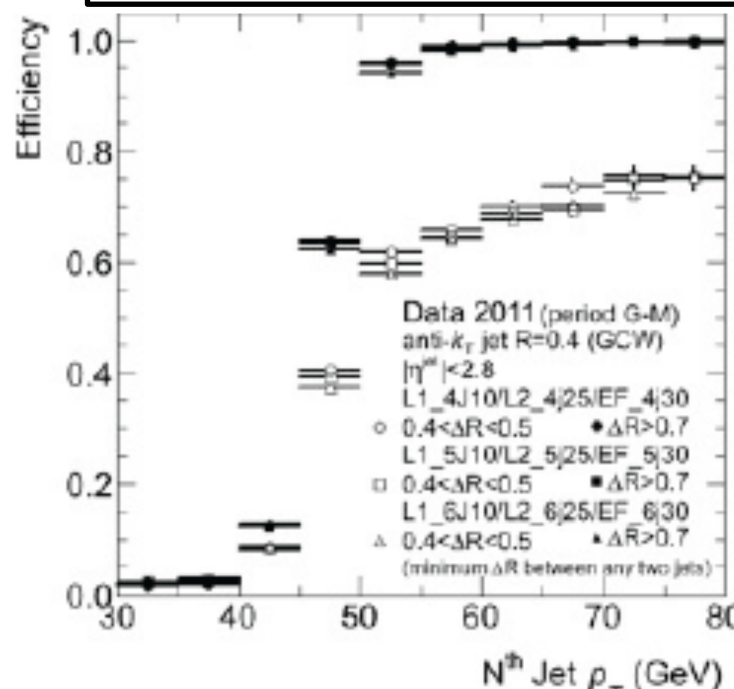
Conclusion: The use of shower shape cuts at Level 1 lowers output trigger rates keeping high physics acceptance.

Potential improvements for Jets?



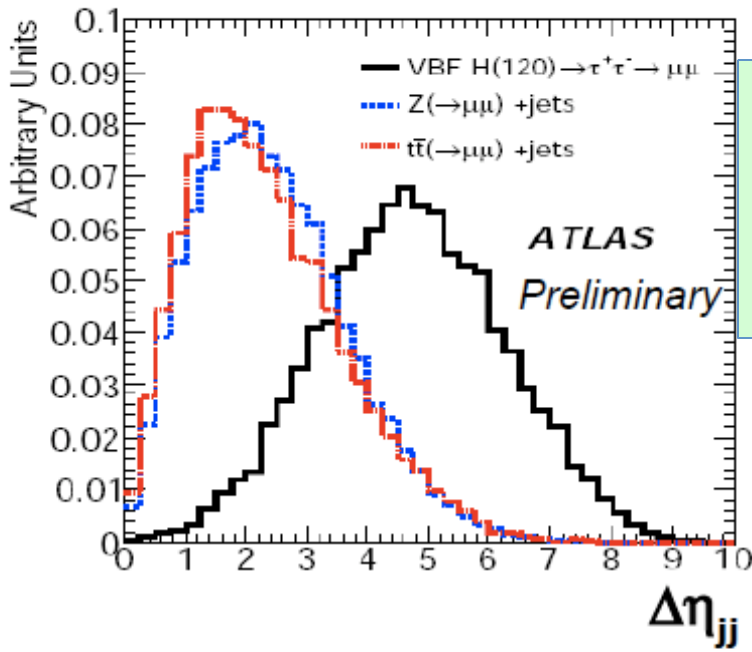
20 GeV Jet Trigger Efficiency
For different pile-up conditions

Multi-Jet trigger Efficiency with different angular separation



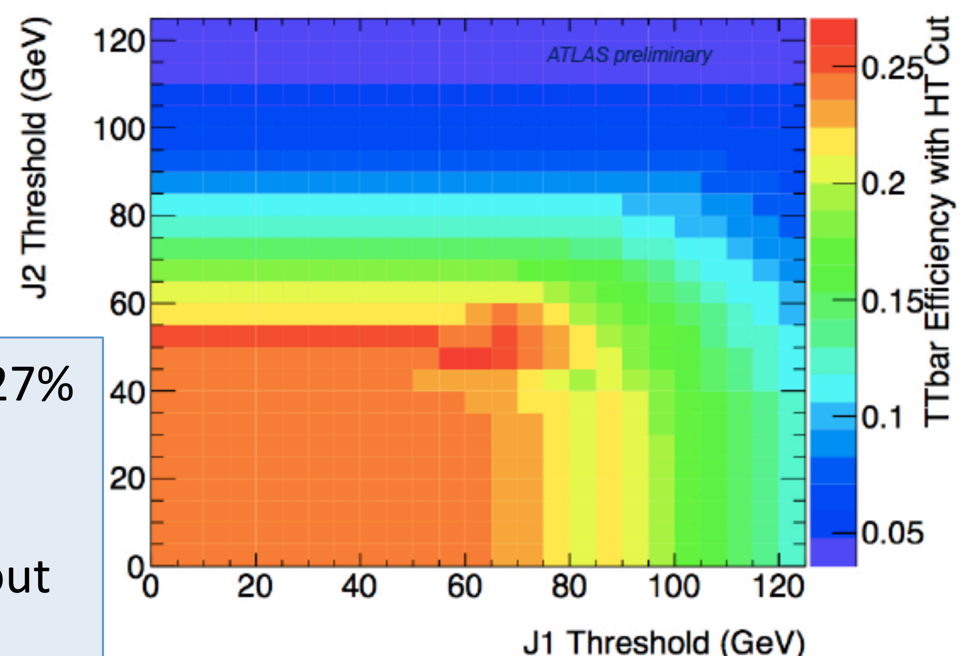
Studies ongoing: Possibility of deploying Sophisticated algorithms at L1 (instead of Cone based) to overcome this.

The potential capabilities of a topological processor at Level 1:



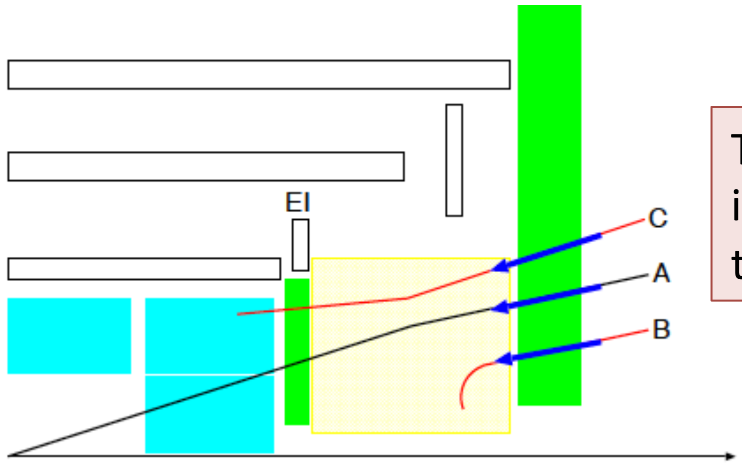
Rapidity separation between jets in VBF Higgs Production compared to some SM processes
Currently deployed in ATLAS at HLT,

- ➢ where it provides a rejection ~ 300.

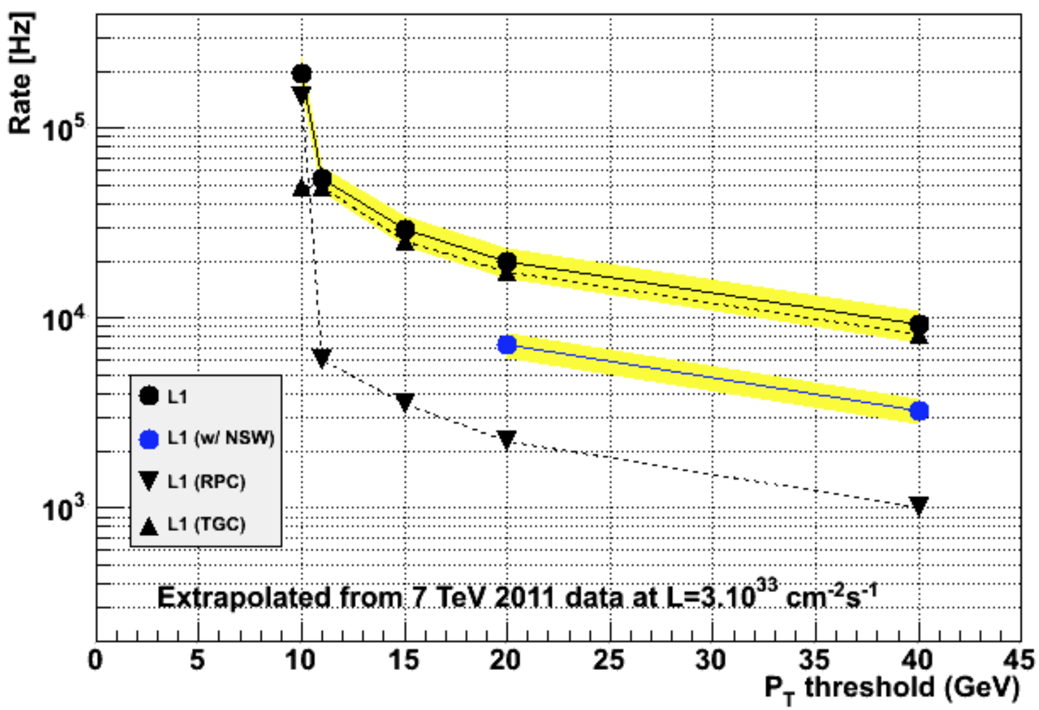


Efficiency of $t\bar{t}$ improves from 19% to 27% when using an H_T (Sum Jet E_T) cut at Level 1.
Requires finer granularity digital readout of hadronic layers.

Rate reductions achievable using NSW



Track A is a high P_T muon originating from the interaction point. Track B & C are backgrounds that can be removed using the NSW chambers



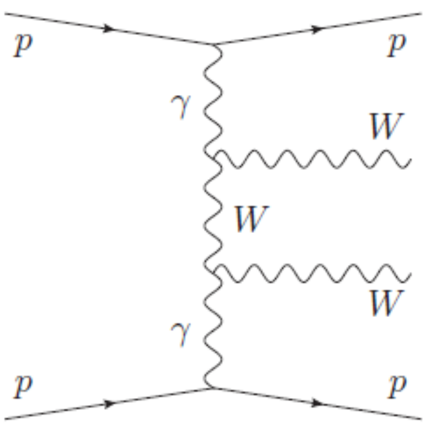
A study of WH associated production: $H \rightarrow \gamma\gamma$, $b\bar{b}$ or $\tau\tau$ & $W \rightarrow \mu\nu$ that relies on a single muon trigger at Level 1

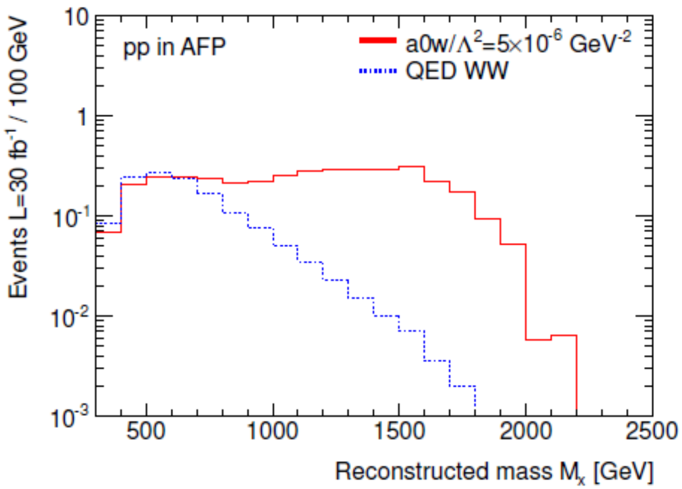
Trigger	Efficiency (%)	Rate (kHz)
$p_T(\mu) > 20$ GeV	82	40
$p_T(\mu) > 40$ GeV	50	15
$p_T(\mu) > 20$ GeV with NSW	78	18

Conclusion: The use of new small wheel (NSW) chambers at Level 1 maintains high physics acceptance at affordable trigger rates.

Physics with AFP

Tag two forward protons to either look at $\gamma\gamma \rightarrow WW$,
or diffractive Pomeron-Pomeron exchange
Good timing resolution (10 ps) essential to overcome pile-up issues.





By looking at the reconstructed recoil mass of WW, one can reach high sensitivity to new quartic $\gamma\gamma WW$ couplings providing a probe into new physics beyond the Standard Model.

Conclusion

As the recent Higgs results from LHC have demonstrated:

- **Every event counts**! Not just for discovery but for precision measurements too: It has taken the Tevatron over a decade to precisely characterize the top quark after its discovery.
- Running longer is not a cost-effective solution.

The current detector cannot operate in post-Phase 1 era without severely compromising the physics capabilities

The Phase 1 upgrades, proposed based on our experience with the ongoing run and extrapolations to future beam conditions **will** restore and enhance the physics capabilities of ATLAS.

The U.S. holds intellectual and leadership roles based on past and current experience and extensive R&D investments.

The subsequent speakers will lay out the scope of the proposed upgrade activities, U.S. interests and cost estimates.

The time has now come to embark on this upgrade path.